7.14 POLARIMETRIC UPGRADES OF THE NOAA'S WSR-88D RESEARCH AND DEVELOPMENT RADAR

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1. INTRODUCTION

The WSR-88D (NEXRAD) radar system is a national network of weather surveillance Doppler radars serving the National Weather Service (NWS), the Air Weather Service (AWS), and the Federal Aviation Administration (FAA). Operational utility of these meteorological radars has encouraged users' demand for additional capabilities. Thus many parallel efforts are underway to resolve deficiencies and implement new features and enhancements.

This paper is an update of the work undertaken by the National Severe Storms Laboratory (NSSL) to improve rainfall measurements by adding a polarimetric capability to the research WSR-88D designated KOUN1.

2. POLARIZATION DIVERSITY

Recent experiments with dual-polarized Doppler weather radars have demonstrated great potential in solving a variety of problems in operational meteorology. The following is a list of what dual polarization can do:

C Improve quantitative precipitation estimation
C Discriminate hail from rain, possibly gauge hail size
C Identify precipitation type in winter storms
C Measure precipitation in the presence of ground clutter
C Identify electrically active storms
C Identify presence of insects, birds, and chaff
C Improve the accuracy of VAD winds
C Provide initial conditions and constraints to numerical models
C Identify aircraft icing conditions

Common polarization bases are linear and circular. Two orthogonal polarizations, horizontal H and vertical V comprise the linear basis whereas left and right hand circular comprise the circular basis. Considerations that led to the basis choice and few optionsf for engineering the system are described next.

Most hydrometeors have their largest dimension horizontal. Hence there is relatively little coupling between the H,V waves as they propagate permiting directs measurement of the backscattering coefficients. On the other hand, circularly polarized waves couple strongly and propagation effects must be accounted for to obtain the backscattering coefficients.

In the circular polarization basis the reflectivity would have to be obtained by summing the outputs of two orthogonal channels. If there is no switching (between left and right circular polarizations) the specific differential phase is obtained from two terms; a term that contains the correlation between the usually strong co-pol signal and a much smaller cross-pol signal, and a term that is the difference between these signals. This would inevitably cause problems in weaker showers. But, with circular polarization the cross-polar signal does not depend on the orientation of hydrometeors, furthermore in combination with the co-polar signal it leads to the measurement of the mean apparent canting angle. This advantage is overcome by what linear polarization offers for quantitative measurements of precipitation. Therefore, our choice rests with the linear H,V basis.

Several options exists for implementing the linear polarization basis. The microwave circuits in the KOUN1 will be flexible so that promising polarimetric schemes can be tested. Scientists at NSSL, NCAR and CSU have experience with switchable linear H,V polarizations wherein a high power ferrite switch is used. This arrangment has defficiencies that promted other approaches. NCAR has implemented a mechanical switch for the transmitted waveform and uses two receivers. CSU has two transmitters, each alternately servicing the H and V ports of the antenna. CSU has also tried simultaneous transmission of H and V polarizations with switched reception. We have proposed simultaneous transmission and reception of the H,V polarizations. It will be possible to change to the single polarization (H) presently transmitted by the WSR-88D so that other improvements of that system could be tested. Simultaneous transmission and alternate reception will also be tested and, if needed, our configuration could accommodate a high power switch as well. Brief description of the reasons for our decision follows.

Alternate transmission and reception offers a benefit in measuring velocities of odd trip scatterers. The even trip (2nd, 4th, etc) echoes are orthogonal to the odd trip echoes. Therefore the second trip echo, usually stronger than other higher trip echoes, is suppressed by over 20 dB with respect to the first trip echo. Another favorable element is that depolarization ratio can be measured. Three disadvantages of switched polarization come to mind. One is the requirements for longer dwell times to make estimates of the polarimetric variables. Two is the reduction of the Nyquist velocity interval for ground clutter canceling; filtering needs to be done separately on the H and on the V returns. Thus the notch at 0 velocity also occurs at integer multiples of the unambiguous velocity v_a (in the non polarimetric mode the notch repeats at $2v_a$ intervals). The third disadvantage is the switch itself. It is an exotic and costly addition to the hardware that would also add to the maintenance. It also introduces losses, limits cross polarization measurements to levels above -20 dB, and would increase the already bulky documentation of the hardware.

Simultaneous transmission and reception can have two

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receivers that share several common components, but a single receiver can also do the job as will be explained shortly. The dwell time for computing polarimetric variables is reduced, the ground clutter filter is not affected, and maintenance is simpler. On the down side, the depolarization ratio can not be measured simultaneously with other polarimetric variables but, if desired, it can be measured together with the standard spectral moments in separate volume scans. Having two receivers offers some redundancy that might be advantageous. Over the lifetime of the system simultaneous transmission should cost less than that incurred with the switch. In the simultaneous transmission mode, the power in each polarization is one half of the power that is transmitted in single polarization. Thus a 3 dB loss in SNR would occur which would be partly compensated for velocity estimates due to the doubling of the number of samples. Although this design requires two receivers, it provides full WSR-88D compatibility. That is, all current data acquisition modes and scanning strategies can remain as they are, and the impact of polarimetric implementation on the existing algorithms and products should be minimal, if any.

The least expensive way to obtain dual polarization is by transmitting simultaneously the H,V samples and receiving alternately the H and V echoes. But the increased dwell time, doubling of the clutter filter notches, and the loss of sensitivity raise concerns that need to be addressed. The versatility of our design coupled with relative ease of programing the signal processor will allow us to test this variant of simultaneous transmission.

3. ANTENNA ASSEMBLY

An engineering evaluation was made to determine if the existing antenna assembly could be used as is for the dual polarization mode. It was meant to guide us in the selection of hardware for upgrading the WSR-88D to polarimetric capability. The current assembly has a feed supported by three struts. This geometry presents a blockage of radiation that affects differently the horizontally and vertically transmitted fields. Four struts (used by research radars) symmetrically located 90 deg apart starting at 45 deg comprise a symmetric configuration with respect to vertical and horizontal electric fields. Therefore, a better match of patterns is achievable, but, the sidelobe ridges in this arrangement are larger than for the three strut geometry. As each strut causes a sidelobe ridge in the plane perpendicular to the strut, a four strut configuration would create two sidelobe ridges, each 6 dB higher than any of the three ridges caused by the three strut configuration. This is confirmed by measurements made on the new antenna of the CSU-CHILL radar. Therefore, we decided to test the existing three strut configuration. One of the struts was a waveguide, we replaced it and a support strut with waveguides that were in use while the radar had circular polarization.

A dual port antenna feed was purchased from Andrew Canada (the company that manufactured the WSR-88D antenna) and installed on the radar. An additional elevation rotary join and associated waveguides to connect it to the feed were also installed. Finally a dual azimuthal rotary joint was mounted. Waveguide switches and microwave assembly to allow simultaneous transmission of H and V components as well as transmission of the single polarization component are being added.

4. ANTENNA PATTERNS

Radiation pattern measurements of a number of WSR-88D antenna without a fully assembled radome have been made by Andrew Canada Inc. on an antenna range. Because no pattern measurements were made of any WSR-88D antennas on site, it was imperative to make measurements on the KOUN1 antenna before the feed was changed to one with a dual-port. These pattern measurements can be compared to the ones obtained with the new feed and can be used to determine if there were significant changes from the patterns measured by Andrew Canada.

A data logger was fed with analogue voltages corresponding to the outputs of the elevation and azimuth encoder and with the log receiver output. A standard gain horn atop a 385 m building and 3444 m away from the radar was used as a source. After considerable processing and calibrations of the logger data, patterns of the KOUN1 were generated. Measurements where made at the lowest elevation for 360^o in azimuth and at higher elevations (to 10^o) in an azimuthal sector from -10^o to 10^o with respect to the boresight. The pattern in the horizontal plane (Fig. 1) demonstrates the fine quality of the antenna before change of feed.

After the change of the feed, pattern measurements were made for the horizontal (Fig. 2) and vertical polarizations (Fig. 3) in the horizontal plane, and for both polarizations in the lower half of the vertical plane (Fig. 4). It is comforting to note that the H pattern of the new assembly (Fig. 2) is very close to the pattern of the previous antenna (Fig. 1).

For polarimetric measurements it is desirable to have a good match of main lobes at horizontal (H) and vertical (V) polarizations. Both copolar patterns have low sidelobe levels and are well matched in the mainlobe (compare Figs 2 and 3). Beamwidths are 0.93^o for the horizontal copolar and 0.90^o for the vertical copolar patterns. The match of patterns in the lower half of the vertical plane (Fig. 4) is excellent, it even extends to several sidelobes. This measurement is alsmot free of multipath returns because the antenna mainlobe was pointed up and away from the ground. We have also examined contours of the ratio P_H/P_v (in dB) about the beam axis (i.e., for points below the boresight where antenna gain >-20 dB). For the most part the patterns agree within ±1 dB, and the match is best where the gain is largest (i.e., near the beam axis). For the points far removed from the axis the difference is larger as expected, but because the antenna gain is much smaller in these regions, the difference is much less significant than close to the axis.

Cross polarization patterns were also recorded. In Fig. 5 is the horizontal cross-polar pattern (i.e., the source is transmitting V polarization and the antenna is receiving H polarization). The WSR-88D specification of < -30 dB of cross-pol signal is met. The cross-polar pattern at vertical polarization matches in shape the cross-polar pattern at horizontal polarization but the amplitudes are about 4 dB higher (still within the measurement uncertainty).

Because the peak of the cross-polar pattern is observed along the boresight, there was concern that it might be related to incorrect orientation of the feed about its axis. This would cause simultaneous transmission of both H,V polarizations. In order to minimize the effects of cross-polar coupling due to terrain scatter, we made tilt measurements atop the KCRI tower located about 300 m from the KOUN1 tower. This places the radiation source in the near field of the antenna where the radar beam is still collimated (it is essentially cylindrical in shape) and the angle to the terrain is several degrees below the beam axis (compared to about 1 deg for the location of the source during the pattern measurements). We rotated the standard gain horn until a null was established and this rotation angle was recorded. With the H port connected to the receiver, the tilt is zero deg within the accuracy of measurement (i.e., about ±0.1 deg). With the rear port V connected, the tilt is also about zero within the measurement accuracy.

5. CONCLUSIONS

Progress to date on the addition of dual polarization capability to the NOAA's research and development radar has been reported. This includes the decision for the choice of the linear H,V polarimetric basis and the options to implement this choice. We have also reported measurements of the antenna patterns, changes in microwave circuits, and modifications of the antenna assembly. Measurements of the patterns prior and after the change indicate that the differences of patterns at horizontal polarizations are negligible. Patterns of co-polar H and V polarizations are well matched to -20 dB from the peak and the cross-polarization patterns are <-32 dB below the copolar peaks. Overall changes to accommodate the H,V polarization did not degrade the patterns.

6. ACKNOWLEDGMENTS

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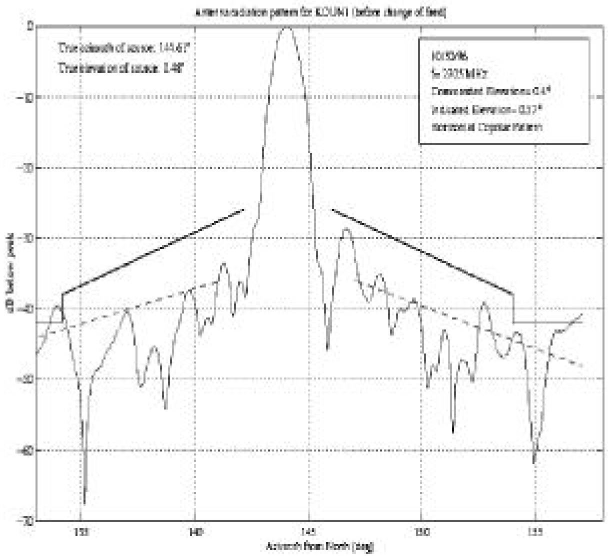

Fig. 1 The pattern over a ±13° azimuthal interval about the beam axis. The solid lines are the specified limits of the sidelobe levels; the dashed lines , obtained from Andrew Canada measurements, are estimated sidelobe envelopes of a newly fabricated WSR-88D without radome.

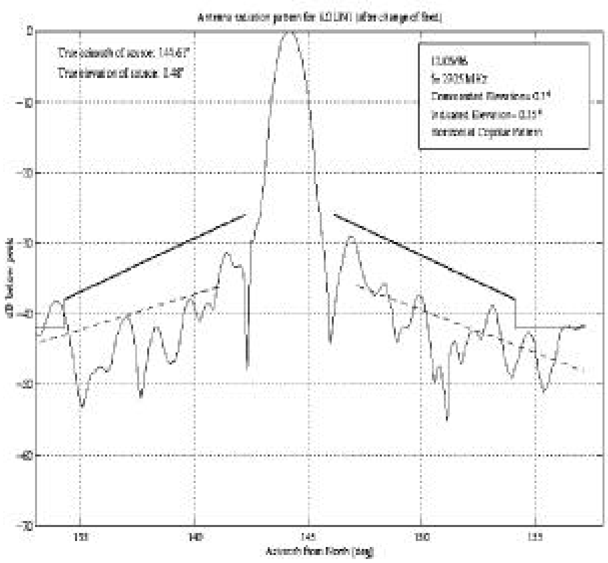

Fig. 2 Same as Fig. 1 but the measurement is made after the change of feed, polarization is horizontal.

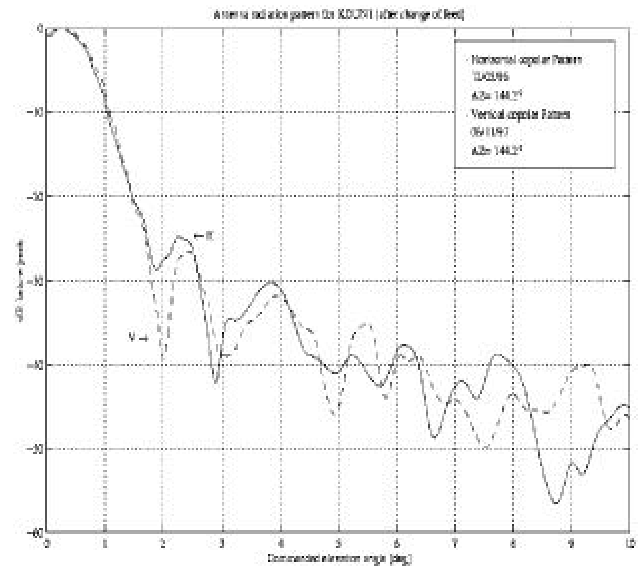

Fig. 4 Antenna patterns of the KOUN1 after change of feed. The scan is along the elevation angle and the polarizations are indicated.

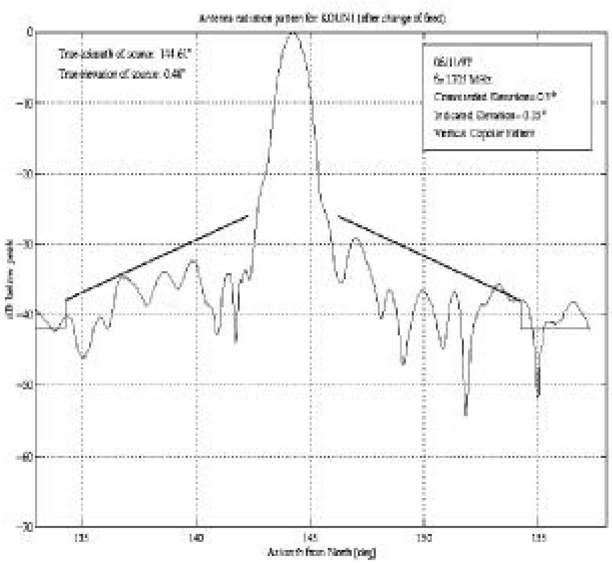

Fig. 3 Same as Fig. 1 but the measurment is made after the change of feed, polarization is vertical.

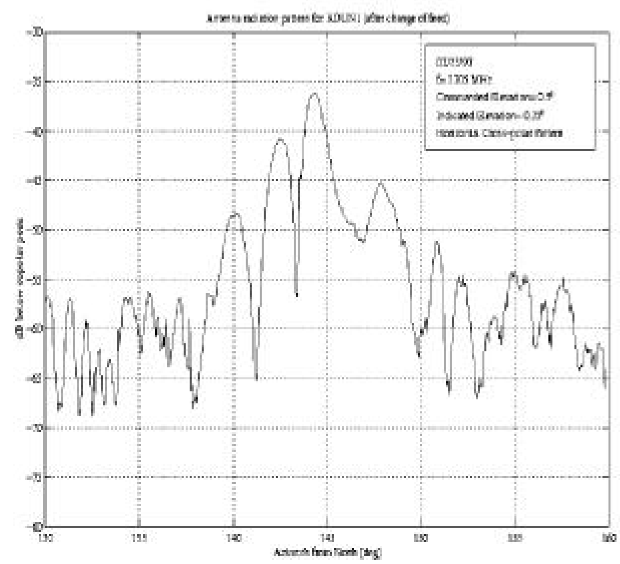

Fig. 5 Cross-polar pattern after change of feed. The source was transmitting vertical polarization and the antenna port for horizontal polarization was connected to the receiver.